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FURTHER INVESTIGATIONS OF CONCENTRATION OF RAW SLUDGE

by J. F. Laboon, M. ASCE

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FURTHER INVESTIGATIONS OF CONCENTRATION OF RAW SLUDGE

J. F. Laboon, Chairman of Board and Chief Engineer
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At the 1951 annual meeting of the Federation of Sewage and Industrial Wastes Association in St. Paul, Minn., (1) the author presented a paper, making public for the first time, laboratory and pilot plant findings substantiating a method of concentrating raw sludge by flotation.

The data contained in that paper and the conclusions reached were based upon results of a year of laboratory investigations and an additional year of pilot plant operation. This information was considered sufficiently conclusive to be formally accepted by the consulting engineering firm of Metcalf & Eddy and to be incorporated as a process in the plans for the proposed sewage treatment plant for the Pittsburgh, Pa. area.

However, even though the data obtained up to September of 1951 was considered sufficient to be used as a basis of design, the pilot plant was kept in operation eight more months to further confirm the findings and to develop other data, if possible, relating to the concentration of raw sludge. No doubt improvements in the method will be made and variations of the process which will make it adaptable to existing plants may be possible. Any additional information about the behavior of raw sludge undergoing concentration by flotation will be of value in ironing out kinks in the process which undoubtedly will develop once full scale operation is under way. Laboratory experiments were continued when the pilot plant was dismantled after 20 months operation.

Two hundred and five additional 5-day concentrations confirmed the original findings that raw sludge can be concentrated to advantage by flotation. The concentrations achieved during this period were from a raw sludge average of 3.5% total solids to a concentrated sludge average of 15.8% total solids with average reduction in volatile matter of 1.9% from 78.9% to 77.0%. This brought the total pilot plant 5-day concentrations to 399 with an average of 17.7% total solids from a raw sludge averaging 3.7% total solids and an average reduction in volatile content of 1.3% from 75.5% to 74.2%. Figure 1 shows the results of the final 8 months of operation.

It will be remembered that in the work reported in the earlier paper it was found that generally the higher the total solids content of the raw sludge the higher the total solids content of the concentrated sludge.

Illustrating this point, it is noted that the 5-day concentration of 205 laboratory samples averaging 3.5% total solids in the raw sludge gave an average of 16.3% total solids in the concentrated sludge, a ratio of 4.65 while 39 sample averaging 8.2% total solids in the raw sludge concentrated by flotation to an average total solids content of 20.4%, a ratio of 2.5.

Comparative results of laboratory and pilot plant concentrations have shown that slightly higher total solids contents were achieved in the pilot plant than in the laboratory. Since it is expected that raw sludge of an average total solids content of 8% may be obtained from primary sedimentation in a large plant, it is not unreasonable to expect a concentration of the raw sludge by flotation to a total solids content of 20%.

During the initial period of pilot plant operation the subnatent liquor from the concentration tanks was discharged directly to the sewer. At the end of approximately 6 months operation the subnatent liquor was returned to the influent end of the preaeration-grit chamber to determine what, if any, deleterious effect on the flotation process resulted from this change and whether the effectiveness of sludge flotation was reduced due to the cumulative effect of fine solids contained in the subnatent. After almost 3 months operation on this basis, pre-chlorination was initiated in an attempt to reduce odors resulting from the subnatent return. Ten days later, or more than 3 months after its initiation, when analyses demonstrated that there was no diminution in the process resulting from subnatent return, the subnatent was again discharged to the sewer.

Other interesting information was found upon analysis of the data during these periods. When neither the subnatent liquor was being returned nor prechlorination was being practiced the average concentration of the sludge was 17.4% total solids. During the period when the subnatent liquor was being returned to the preaeration tank, but without pre-chlorination, the average total solids content of the concentrated sludge was found to be 19.0%.

During the period of ten days when both subnatent liquor return and prechlorination was being practiced, the concentration of the sludge dropped to 17.9% total solids. Finally, when pre-chlorination was being applied, but subnatent no longer was being returned, the total solids content of the concentrated sludge made an additional drop to 16.1% total solids. The tabulated data follow:

		@ Total Solids		
		Raw	Conc.	Ratios
Prior to June 13, 1951	No chlorine. No Liquor Return. (101 Samples)	3.9	17.4	4.5
June 13, 1951 to September 10, 1951	No Chlorine. Liquor Returned. (85 Samples)	4.2	19.0	4.5
September 10, 1951 to September 20, 1951	Chlorination. Liquor Returned. (10 Samples)	3.4	17.9	5.3
After September 20, 1951	Chlorination. No Liquor Return. (201 Samples)	3.8	16.1	4.2

This would seem to indicate that the liquor return acted as a biological seeding material, stimulating the production of gas in the concentration tanks and producing a concentrated sludge of high total solids content.

On the other hand, the application of chlorine apparently tends to retard biological activity in the concentration tanks and to partially offset the beneficial action of subnatent liquor return. The slightly unfavorable action of chlorine is illustrated by the drop in concentrations during the period when prechlorination was in operation, but no liquor was being returned. The ratios of total solids in the concentrated sludge to the total solids in the raw sludge during the periods when no chlorination and no subnatent return were practiced

and when chlorination only was practiced were 4.5 and 4.2 respectively. Sufficient chlorine was applied at all times to produce a residual of 0.1 ppm in the effluent from the settling tank. This is in excess of actual requirements for bacterial kill and therefore can be reduced in full scale operation. It is believed that chlorination to the extent of meeting the chlorine demand of raw sewage at the influent end of the sedimentation basins will produce the desired bacterial kill. This has been demonstrated in full scale operation at the Buffalo plant. (2)

The effect of pre-chlorination is not considered to be a vital factor since laboratory and pilot plant results indicate that a higher concentration may be expected as the total solids of the primary sludge become greater. Therefore, it has been assumed that an average concentration of 18% solids is a conservative expectation with primary sludge averaging 8% solids even where pre-chlorination is practiced. The adverse effect of pre-chlorination in the proposed treatment plant will be minimized by returning the subnatent liquor from the concentration tanks to the grit chambers as well as by reduction in chlorine requirements based on bacterial kill.

Laboratory tests on the filtration of 2-day concentrated sludge were undertaken to determine if filtration of concentrated sludge without chemical conditioning could be done without diluting the 5-day concentrations which was found necessary with the pilot plant filter early in the experiments. The results were very encouraging and will be published in another paper.

Laboratory investigations into the B.O.D. of both raw and 5-day concentrated sludges failed to reveal any relationship between the B.O.D. of such sludge and their volatile content and/or their concentration period. The only consistent factor found in the results of these tests was the increase in B.O.D. of the sludge during the concentration period. This may be explained by the hypothesis that sludge contains complex organic compounds which exhibit no 5-day B.O.D., but during the 5-day concentration period, these complex organic structures requiring little or no oxygen are broken down into simpler structures by biological or chemical action. These simple compounds will then have a 5-day B.O.D. Thus the B.O.D. of concentrated sludge will be greater than that of raw sludge.

Minneapolis-Saint Paul in 1951 (3) at the suggestion of the author experimented with the concentration of sludge by flotation and came up with the following observations:

1) The sludge after either the 48 hour or the 72 hour period of storage at 37°C had a very foul odor and suitable equipment for the elimination of such odors must be incorporated in any process of this type.
2) Raw sludges can be concentrated to approximately twice their original solids percentage for a 48 hour storage period with a further 33-1/3% increase after 24 hours additional storage.
3) The extent to which concentration is attained is governed by the original raw sludge solids content, volatile content, pH, and hours of storage.
4) The physical appearance of the final heavily compacted sludge mass, 19% solids, indicated that difficulties in handling a material of this consistency might be of prime concern.
5) In general, the volatile solids content and pH of the raw sludge were decreased during concentration with the total solids content and alkalinities showing increases.

Under Observation 3), the exclusion of the effect of temperature is perhaps an oversight.

Several tests using the addition of such compounds as sugars and starches which are favorable to the metabolism and reproduction of gas producing organisms were made. While the addition of such compounds stimulated gas production to such a degree that the sludge-subnatent liquor separation occurred much more rapidly than normally, no appreciable increase in total solids content of the concentrated sludge layer was produced, and the cost of such media would be in excess of the saving in cost which would be made by the reduction in tank capacity due to the shorter concentration period. In one instance the sludge was actually raised out of the liquor and supported on a gas layer.

Laboratory tests of further concentrating raw sludge by draining after the subnatent was drawn off failed to produce a practical method adaptable to full scale operation. This modification utilized the force of gravity to drain the sludge. After 24 hours, the subnatent was removed and the sludge rested on a perforated bottom which opened to atmospheric pressure, allowing the liquor to drain for another 24 hours. The sludge was then removed for analysis. The results were extraordinary. Filter tests were run on the primary sludge and the 48 hour (Control) concentrated sludge used in this test. The comparison of results is shown in Table I. Further investigations with a view to developing a practical method of draining 24 hour concentrated sludge are warranted.

An experiment, designed to show that the time required for initial separation and flotation in the concentration process is due largely to entrapped gases rather than to continuing or stimulated biological activity, seemed to confirm this hypothesis. This experiment also demonstrates clearly that temperature is the chief factor affecting the time for flotation. Liter graduate cylinders were used as concentration vessels for the sludge being investigated, except for the 50°C . samples which were held in 500 ml. graduates. These were used to facilitate taking liquor depths and volumes to determine the time of initial separation of the sludge from the liquor. All the sludge samples used were collected at the same time from the Penn Township, Pa. treatment plant, and analyzed at 5.2% total solids and 77.6% volatile solids. The temperature of the raw sludge was 22°C. at the time of placing in the constant temperature baths. Control samples were set up for 5°C., 20°C., 35°C. and 50°C. In addition, samples after being subjected to negative pressures of 8, 12, 16, 22 and 24 inches of mercury were placed in the 35°C. and the 50°C. temperature baths. The control samples held at 5°C. showed no signs of rising after 300 hours. In fact, the sludge had settled and had a clear top liquor of approximately 40 ml. The control samples held at 20°C. produced 5 ml. of subnatent after 25 hours. The control samples in the 35°C. bath had 3 ml. of subnatent after 1.75 hours and the control samples held at 50°C. took only 30 minutes to produce 15 ml. of subnatent liquor.

The behavior of these control samples at various temperatures illustrates clearly the importance of the effect of temperature on the length of time neccessary to float raw sludge. It also supports the theory that the time required for initial separation of sludge and liquor depends on the quantity of dissolved or entrapped gases which are present at the time the sludge is placed in the concentration tank. This is substantiated by the fact that the higher the temperature the faster the sludge-subnatent liquor separation takes place, indicating that the dissolved gases are expanded rapidly with rising temperatures resulting in increased buoyancy of the mass of sludge.

Even though rises in temperature generally increase biological activity and reproduction, it is the opinion of the author that such activity cannot be sufficiently stimulated to result in the production of sufficient gas to float the

sludge in 30 minutes as is the case of 50°C. It is an accepted fact that changing the environment of biological activity by material temperature changes creates a temporary lag until activity can be resumed under the new environment.

Generally, at a given temperature, the greater the vacuum the raw sludge was subjected to, the longer it took for the sludge-subnatent liquor separation to occur. This would also tend to substantiate the premise that dissolved or entrapped gases are also a factor in the time required for initial sludge flotation (Table II). As the vacuum is increased the greater is the removal of the dissolved and entrapped gases from the sludge and the less will be their buoyant effect in the sludge mass. There was only a slight effect on flotation with a vacuum of 16 inches and less.

A series of laboratory experiments was initiated to determine the effect of adding digested sludge to raw sludge in the concentration process. Detroit (4) published the results of one experiment using the remains of concentrated sludge to seed raw sludge in one of the grit channels used to simulate a concentration tank. No relative quantities of seeding sludge and primary sludge were given, although it was indicated that the primary sludge had an average total solids content of about 12% which is considerably higher than is obtainable from small local sewage treatment plants. The concentrated sludge analyzed 24.8% solids and 47.4% volatile after 120 hours.

The results obtained from laboratory experiments designed to determine the degree of concentration obtainable by seeding with various amounts of digested sludge have yielded interesting results. The 24 hour concentrations produced the greatest increases (3.3%) and the 96 hour concentrations the least (0.3%) as compared with the control samples in the seeding range of 15% to 50% using a raw sludge containing approximately 6% total solids. However, an insufficient number of tests have been performed to date to justify definite conclusions as to the value of seeding raw sludge with digested sludge to improve concentration by flotation. The average results of these tests appear in Table III. The comparison of raw and seeded sludge concentration ratios for various concentration periods, as well as for several different quantities of seed, is illustratediin Figure II. These experiments will continue until definite conclusions are reached.

Acknowledgement

The efforts of Mr. C. Fred Abel, Chief Chemist, his staff, and of Mr. Harold J. Dickman, Construction Engineer, involving many disagreeable tasks which they performed in the laboratory and at the pilot plant are gratefully acknowledged.

Conclusions

1. The extended pilot plant and laboratory studies have definitely confirmed that sludge concentration by flotation as pre-treatment for incineration is feasible, from an operational standpoint.

2. Pre-chlorination, when practiced at the pilot plant without subnatent liquor return had a slight deterrent effect upon the flotation process. However, in the proposed treatment plant the subnatent liquor return and reduced chlorine dosage will offset the effects produced at the pilot plant.

3. Laboratory filtration tests have shown that sludge concentrated for 48 hours reaches a concentration which can be handled by conventional

methods and can be filtered on a filter leaf without the need for dilution, which was found necessary when filtering 120 hour concentrated sludge (1). No conditioning chemicals were used.

4. Standard 5-day B.O.D. examinations of raw and concentrated sludge failed to produce results of value, probably because of the difficulties encountered in getting a representative sample sufficiently dilute to be tested according to Standard Methods.

5. Tests employing various sugars and starches as seeding compounds failed to increase the solids content or to reduce the time required sufficiently to economically justify their use.

6. Investigations into seeding with digested sludge show promise of accelerating flotation as well as producing slightly higher concentrations, but additional tests are necessary before definite conclusions can be reached.

7. Tests of a modification employing gravity draining of sludge resulted in such high total solids content that it is felt that further investigations directed toward solving the mechanical difficulties of the modification are warranted.

8. The importance of the role of temperature as a major factor in determining the length of time necessary for the separation and flotation to take place has been reaffirmed.

9. The gases dissolved or entrapped in the sludge mass at the time the sludge is placed in the concentration tanks play an important part in the time required for initial separation and flotation.

References

1. J. E. Laboon - Experimental Studies on the Concentration of Raw Sludge, S. and I. W. Vol. 24 (1952) p. 423.
2. 1951-52 Annual Report of the Buffalo Sewer Authority.
3. Nineteenth Report of the Minneapolis-Saint Paul Sanitary District for the year 1951.
4. 100th Annual Report of the Department of Water Supply, City of Detroit, for fiscal year ending June 30, 1952.

TABLE I

ADDITIONAL CONCENTRATION BY DRAINING

TOTAL SOLIDS %

Sample Number	Primary	Control 48 Hour Concentration	24 Hour Concentration Plus 24 hours For Draining	Primary Filter Cake *	Control 48 Hour Concentration Filter Cake*
439	4.6	11.2	19.2	18.9	16.4
441	5.5	12.7	19.1	18.0	21.0
443	4.7	8.4	16.8	20.9	23.8
446	6.3	14.8	20.9	21.9	24.7
447	5.9	14.4	18.1	21.3	23.8
449	5.3	15.9	23.9	21.3	None Run
Average	5.4	12.9	19.7	20.4	21.9

* By leaf filter without chemicals.

TABLE II

EFFECT OF DE-GASSING ON FLOTATION

Time	Subjected, for 30 min., to indicated negative pressure (Inch. of Mercury)											
	35°C. (1000 ml. Graduates)						50°C. (500 ml. Graduates)					
Hours	0 Control	8	12	16	22	24	0 Control	8	12	16	22	24
0.50	0	0	0	0	0	0	15	0	0	0	0	0
0.75	0	0	0	0	0	0	20	0	0	4	0	0
1.00	0	0	0	0	0	0	35	3	4	7	0	0
1.50	0	0	0	0	0	0	50	15	10	20	0	0
1.75	3	0	0	0	0	0	60	20	15	25	0	0
2.00	10	0	-	0	0	0	70	25	-	30	0	0
2.25	20	0	0	-	0	0	75	30	25	-	0	0
2.50	20	0	1	0	0	0	85	35	30	35	0	0
3.00	30	3	6	5	0	0	100	45	35	60	0	0
3.25	35	8	10	-	0	0	105	50	40	-	0	0
3.50	40	15	35	10	0	0	115	55	65	65	0	0
4.50	50	20	50	20	0	-	125	65	70	75	0	-
5.50	100	50	60	30	-	-	150	90	75	80	-	-
6.50	115	60	70	-	-	-	155	95	80	-	-	-
7.00	135	75	-	-	-	-	165	105	-	-	-	-
7.50	145	85	-	-	-	-	165	115	-	-	-	-
14.50	-	-	-	-	-	0	-	-	-	-	-	0
15.50	-	-	-	-	20	0	-	-	-	-	0	*
16.50	-	-	-	220	40	0	-	-	-	110	*	*
17.50	-	-	250	250	50x	3	-	-	115	115	*	*
18.50	300	250	270	260	80x	30	200	145	120	125	*	*
19.50	325	270	280x	290	90x	40	205	150	125	130	*	*
20.50	335	280	300x	300	100x	60	210	155	130	140	*	*
22.50	370	310	320x	320	100x	70	220	170	140	155	*	*
23.50	380	325	345x	340			225	175	150	165		
24.50	400	350	360x				235	190	155			
25.50	410	360					235	200				

* Liquor formed a layer near the middle of the column. No bottom liquor.

x Sludge beginning to fall back to bottom of cylinder.

TABLE III

LABORATORY TESTS ON CONCENTRATION OF SEEDED RAW SLUDGE

Digested Sludge % Used	Digested Sludge % T.S.	Concentration Time -- Days	Control Raw % T.S.	Control Conc. % T.S.	Seeded Initial % T.S.	Seeded Conc. % T.S.	Number of Samples
0.25	7.8	3	3.7	11.2	4.8	12.1	1
1.0	7.8	3	3.7	11.2	5.4	11.7	1
2.5	5.4	3	4.0	7.8	4.2	8.9	2
5.0	5.4	3	4.0	7.8	4.9	9.9	3
7.5	Lost	3	4.0	7.8	5.1	7.9	1
10.0	15.7	1	7.2	12.8	6.8	9.5	3
10.0	8.4	2	6.7	14.3	7.1	16.4	37
10.0	9.8	3	5.2	16.2	6.2	17.6	20
10.0	16.4	4	5.8	7.9	7.0	14.5	1
12.5	6.1	1	9.5	10.8	8.1	14.0	1
12.5	6.7	4	8.6	20.3	8.3	21.6	1
15.0	11.7	1	5.8	11.1	5.9	11.8	6
15.0	9.3	2	6.5	14.9	6.9	16.3	40
15.0	9.8	3	4.9	14.5	5.9	17.2	24
15.0	9.9	4	7.7	20.5	7.7	19.5	5
20.0	14.3	1	4.9	9.1	6.8	13.3	7
20.0	8.6	2	6.5	15.1	7.0	16.9	35
20.0	10.2	3	4.9	14.5	6.4	17.5	23
20.0	7.8	4	7.7	20.4	7.5	19.1	8
22.5	6.1	3	4.6	14.5	6.5	15.8	1
25.0	8.5	2	6.8	14.1	6.7	15.7	33
25.0	7.7	3	6.5	15.3	6.6	17.6	5
32.5	7.7	1	5.6	8.8	6.3	13.0	1
32.5	9.7	2	7.4	15.3	7.0	15.8	2
32.5	8.3	3	6.1	15.4	6.9	18.6	6
35.0	8.7	2	5.2	12.2	6.9	16.8	1
35.0	8.6	4	7.2	17.4	7.8	19.5	2
37.5	6.0	3	7.5	16.0	7.9	19.2	1

- continued -

TABLE III (continued)

Digested Sludge % Used	Digested Sludge % T.S.	Concentration Time -- Days	Control Raw % T.S.	Control Conc. % T.S.	Seeded Initial % T.S.	Seeded Conc. % T.S.	Number of Samples
40.0	8.2	1	5.2	8.6	6.9	14.3	2
40.0	9.3	2	6.6	14.3	6.8	16.4	3
40.0	8.4	3	6.2	15.5	7.2	18.1	6
40.0	8.6	4	7.2	17.4	7.9	19.4	2
42.5	6.0	1	4.7	10.6	5.9	14.3	1
42.5	6.7	3	6.5	15.4	6.8	17.6	2
45.0	7.7	1	5.6	8.8	6.2	14.7	1
45.0	6.8	3	5.3	15.1	6.3	18.6	3
45.0	8.4	4	9.1	18.6	9.3	20.5	4
47.5	6.0	1	4.7	10.6	5.8	14.3	1
47.5	6.6	3	7.7	15.6	6.9	18.4	1
50.0	8.4	4	9.1	18.6	9.8	20.0	1
55.0	8.4	4	9.1	18.6	8.5	20.6	1
60.0	8.4	4	9.1	18.6	7.5	18.6	1
75.0	6.8	3	5.3	15.1	6.8	16.4	1
		Averages for Seeding Range from 15% to 25% Inclusive					
Average	13.1	1	5.3	10.0	6.4	12.6	13
Average	8.9	2	6.5	14.9	6.9	16.6	78
Average	9.7	3	4.9	14.6	6.2	17.3	53
Average	8.6	4	7.7	20.4	7.6	19.3	13
Average	9.5	1,2,3,4	6.0	14.8	6.7	16.7	157

* * *

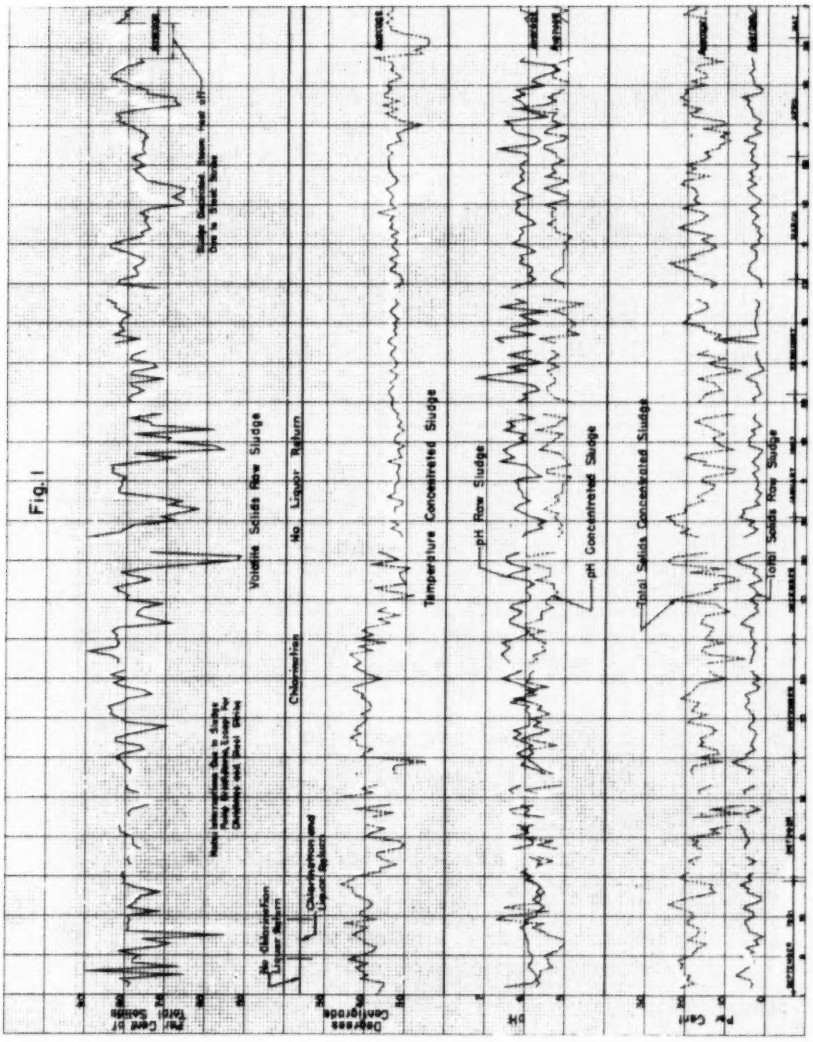
Fig. 1
Volatile Solids Raw Sludge
No Liquor Return
Chlorination
Chlorination and Liquor Return
No Chlorination Liquor Return
Temperature Concentrated Sludge
pH Raw Sludge
pH Concentrated Sludge
Total Solids Concentrated Sludge
Total Solids Raw Sludge

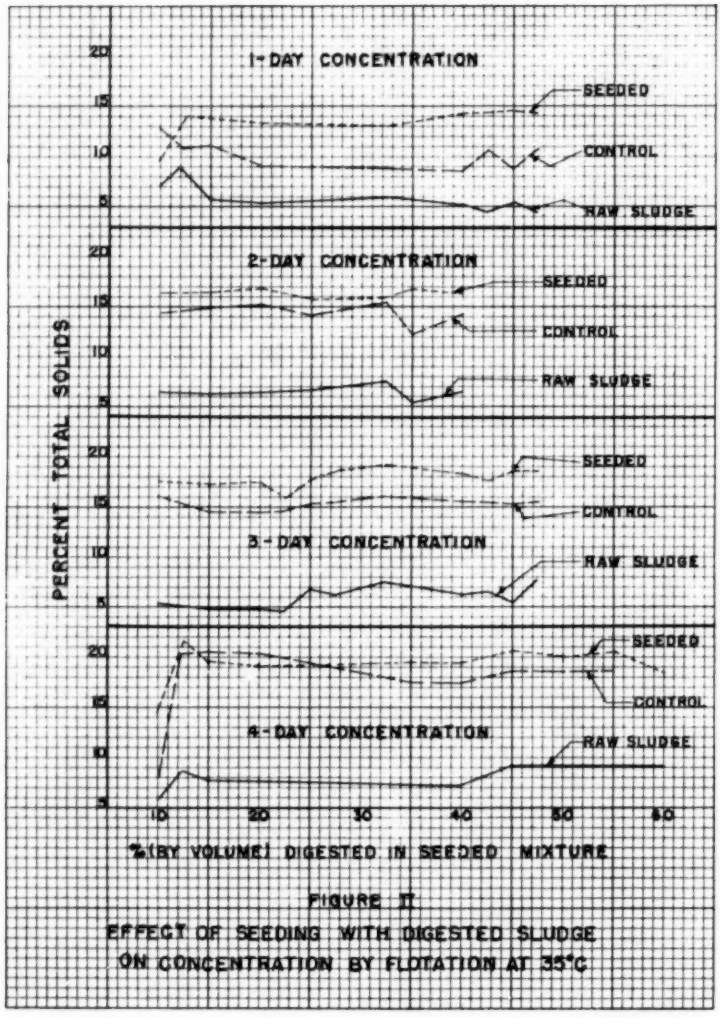

FIGURE II

EFFECT OF SEEDING WITH DIGESTED SLUDGE
ON CONCENTRATION BY FLOTATION AT 35°C

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